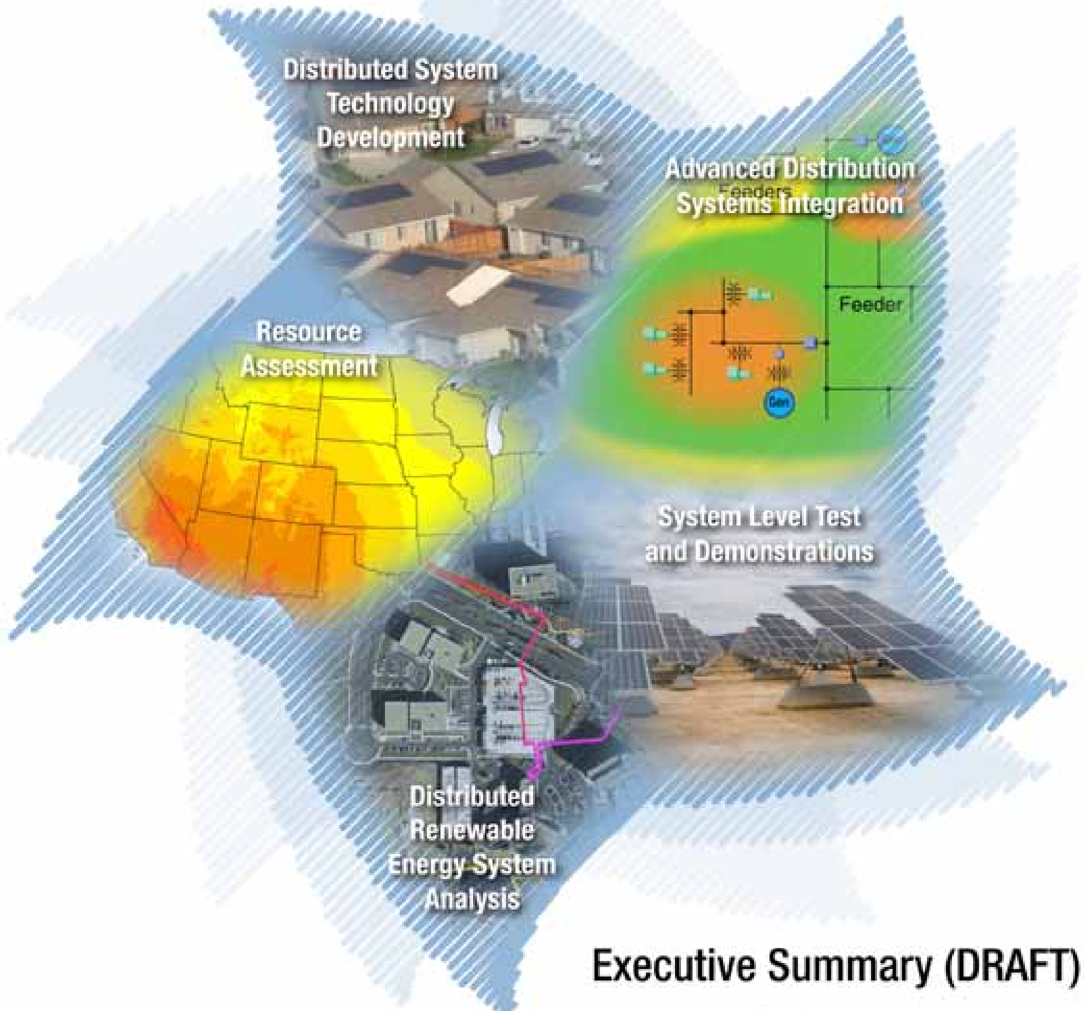
Renewable Systems Interconnection



Executive Summary (DRAFT)

October 2007

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

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Foreword

Now is the time to begin planning for the integration of significant quantities of distributed renewable energy onto the electricity grid. Factors such as growing concern about climate change, adoption of state-level renewable portfolio standards and incentives, and accelerated cost reductions are driving steep growth in U.S. renewable energy technologies. In particular, installations of distributed solar photovoltaic (PV) technology have been and are very likely to continue to grow very rapidly.

An emerging challenge to achieving this market potential, though, is the ability of the electricity grid to handle high penetration levels of distributed PV systems and other renewable energy technologies. The concerns of utilities focus largely on technical issues surrounding grid planning, operations, reliability and safety but there are also broader regulatory and business issues that could directly impact the electric power delivery system and its stakeholders. Put simply, technological advances need to be coupled with consistent codes, standards, and regulatory procedures in order for distributed PV and other renewable energy technologies to achieve their full market potential.

As part of the effort to help distributed renewable energy technologies meet their market potential, the U.S. Department of Energy (DOE) launched the *Renewable Systems Interconnection (RSI)* study during spring 2007. The RSI study consists of 14 individual reports that address issues related to distributed systems technology development, advanced distribution systems integration, system level tests and demonstrations, technical and market analysis, and resource assessment. Given that integration-related issues at the distribution system are likely to emerge first for PV technology, the RSI study focuses primarily on distributed PV.

This document summarizes the challenges, identified in the RSI reports, that must be tackled to enable high penetration levels of distributed renewable energy technologies. Key objectives for the DOE, utilities, regulators, and industry identified in these reports include the following:

- Develop *Solar Energy Grid Integration Systems* that incorporate advanced functionality and active integration with electrical distribution systems and building energy management systems.
- Improve stand-alone capabilities of distributed renewable technologies with storage to improve customer reliability, enhance power quality, and provide backup power functions.
- Utilize prototype testbeds and field deployments to evaluate key characteristics of new renewable energy systems and other distributed technologies.
- Develop and validate best practices and software tools to facilitate transmission and distribution (T&D) system planning and operation with greater deployment of renewable energy systems.
- Establish grid infrastructure design and operation methods for integrating renewable energy into localized energy networks, microgrids, and mini-grids, including utility load/production control methodologies.
- Develop new solar resource forecasting capabilities over a variety of time steps.
- Establish consistent codes, standards, and transparent regulatory implementation practices to ensure safe and effective PV systems integration at high penetrations.

Addressing grid-integration issues is a necessary prerequisite for the long-term viability of the distributed renewable energy industry in general and the distributed PV industry in particular. The RSI study is one step on this path. In addition, the DOE is working with a broad set of stakeholders to develop an R&D plan aimed at making this vision into a reality.

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Summary

Due to growing concern about climate change, adoption of state-level renewable portfolio standards and incentives, and accelerated cost reductions, renewable energy technologies such as solar PV and wind are expected to grow rapidly during the next couple of decades. As these technologies mature, they have the potential to provide a significant share of our nation’s electricity demand.

However, as their market share grows, concern about potential impacts on the operation and stability of the electricity grid may create barriers to their future expansion. Wind power is already gaining considerable market penetration at the transmission level, and its variable nature increases the complexity of operating the bulk power grid. Additional challenges are likely to emerge as additional non-dispatchable sources, such as PVs, are added to the electrical distribution network.

To overcome these potential barriers, the U.S. Department of Energy (DOE) launched the *Renewable Systems Interconnection (RSI)* study during spring 2007. DOE brought together a team of industry experts to address the technical, regulatory, and business issues that have the potential to limit the market uptake of distributed PV and other renewable technologies.

One key finding of the RSI study is that grid integration issues are likely to emerge much more rapidly than many analysts expect; in some regions of the United States, grid-integration related barriers to future growth could emerge within the next five to ten years. For example, in California a number of new subdivisions are currently being built with PV systems as a standard feature on all new homes (see **Figure 1**). With these types of developments already occurring in the marketplace, it is clearly time to begin planning for the integration of significant quantities of distributed renewable energy onto the electricity grid.

Figure 1. Premier Gardens Subdivision, Rancho Cordova, California

Source: Sacramento Municipal Utility District

The U.S. grid-connected PV market has been growing very rapidly during the past five years. Annual grid-connected PV installations have increased from 10 MW per year in 2001 to about 180 MW per year in 2006, resulting in a cumulative installed base of about 480 MW of grid-connected PV in the United States at the end of 2006.

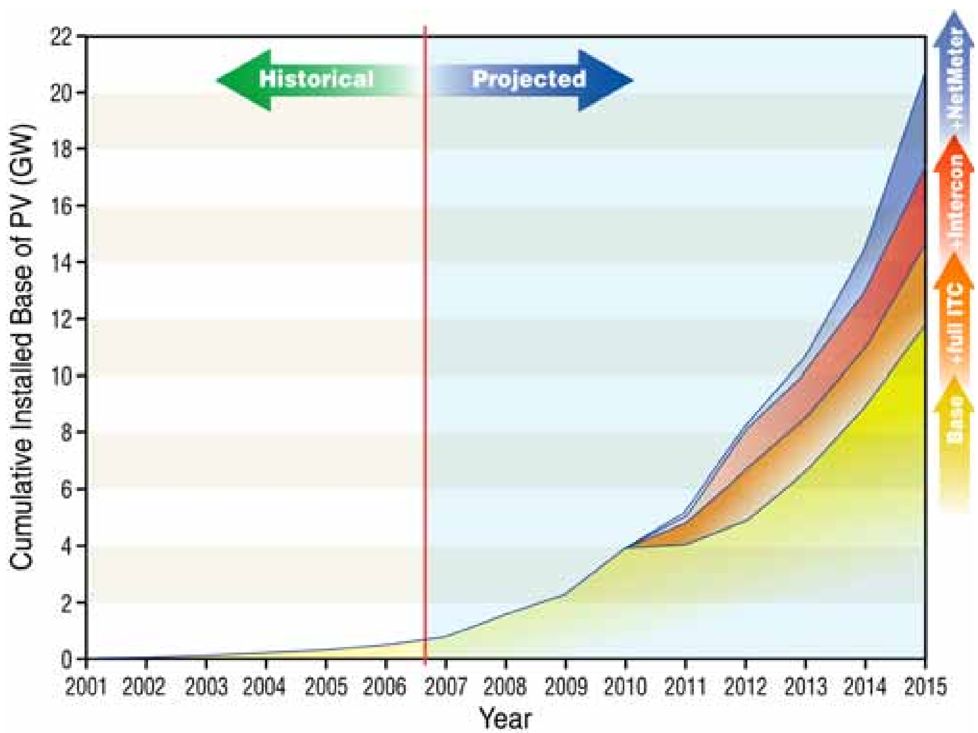
Yet this accelerated growth of the PV industry is simply the tip of the iceberg. Policy developments at both the federal and state level, coupled with technology improvements funded by the DOE's Solar America Initiative, are helping to create a more receptive marketplace for PV in the U.S. Indeed, scenarios developed as part of the RSI study project that annual installations of grid-tied PV in the United States could reach 3.6–6.4 GW by 2015, resulting in a cumulative installed base of 12–21 GW by 2015 (see **Figure 2**).

As shown in Figure 2, three key regulatory and policy drivers were found to have a significant impact on PV adoption rates: extending the Federal investment tax credit (ITC), improving interconnection standards, and lifting net metering caps/establishing net metering.

Extension of the Federal ITC had a critical impact on the PV market, and was found to be a prerequisite for the success of the other policies examined. The Federal ITC is currently set to expire at the end of 2008. However, a number of proposals have been introduced in Congress, including proposals for a partial extension (i.e., through 2010 for residential installations and 2015 for commercial installations), and a full extension (i.e., through 2015 for both residential and commercial installations). Projected cumulative installed PV in 2015 increased from 11.8 GW under a partial extension of the ITC (i.e., the base case shown in Figure 2), to 14.7 GW under a full extension of the ITC.

Improving interconnection standards had a significant impact on PV market development. Many states or utilities currently have interconnection standards that inhibit PV adoption. In particular, the following seven states have been ranked as having "fair" or "poor" interconnection rules by the Interstate Renewable Energy Council (IREC): Connecticut, Delaware, Florida, Maine, Massachusetts, Tennessee, and Washington. Projected cumulative installed PV in 2015 increased from 14.7 GW under existing interconnection rules (with ITC extension) to 17.4 GW under improved interconnection rules.

Figure 2. Grid-Connected Distributed PV Growth, 2001–2006, Projected to 2015
The scenarios shown illustrate the impact of policies such as extension of the federal investment tax credit (ITC), interconnection standards, and net metering on the distributed PV market. The low end of the growth range (base case) assumes a partial extension of the federal ITC, while the high end assumes implementation of a full set of solar friendly policies.



Source: DOE Renewable Systems Interconnection Study: *PV Market Penetration Scenarios Report*

Lifting net metering caps/establishing net metering also had a significant impact on projected PV market penetration in a number of states. The largest impact was in California, where projected cumulative installed PV in 2015 increased by roughly 2 GW when the existing net metering cap was lifted. As shown in Figure 2, combining all three policies is projected to result in a cumulative installed base of about 21 GW by 2015.

The RSI study is organized into 14 distinct reports aimed at identifying and addressing both the technical and analytical challenges that must be tackled to enable high penetration levels of distributed solar, wind, and other renewable energy technologies that interconnect to the grid at the distribution level.[1]

By combining analysis of renewable technologies, storage, controls, and other appropriate technologies, the RSI study is striving to build the foundation for allowing a high penetration renewable energy future while enhancing the operation of the electricity grid. In addition, by directly engaging utilities and other stakeholders in this process, the RSI study can boost the confidence of regulators and utilities regarding the electricity industry's ability to maximize the use of renewable energy technologies.

The RSI study reports include:

- ***Advanced PV System Designs and Technology Requirements***. This report develops a set of conceptual system designs that integrate PV, storage, and control technologies for residential and commercial market applications. These *Solar Energy Grid Integration Systems (SEGIS)* will incorporate advanced functionality and integration with electrical distribution systems and building energy management systems, thus enabling utilities and/or system owners to realize the full value of the systems.
- ***Advanced Grid Planning and Operations***. This report describes research and analysis on advanced grid planning and operations needed to facilitate large-scale integration of distributed PV into the distribution system.
- ***Utility Models, Analysis, and Simulation Tools***. This report reviews current utility studies, models, and software applications that are used in grid planning and identifies needs for new analytical tools to address high levels of PV in the electric grid.
- ***Development of Analysis Methodology for Evaluating the Impact of High Penetration PV.*** This report explores the impact of high levels of PV penetration on standard utility system planning methodologies and outlines how these methodologies are changing (or could be modified) to enable effective integration of renewable generation.
- ***Distribution System Performance Analysis for High Penetration PV***. This report analyzes issues with interconnecting various penetrations of PV on the distribution system and focuses on voltage regulation needs.
- ***Renewable Systems Interconnection Security Analysis.*** This report examines the potential security implications resulting from high penetrations of PV that will utilize high degrees of

[1] Draft reports are being distributed during October 2007 for external peer review, and final reports will be published during December 2007.

information technology and control systems. This analysis will provide the basis for designing more inherently secure systems rather than incorporating security as an afterthought

- ***Enhanced Reliability of PV Systems with Energy Storage and Controls***. This report examines the use of energy storage and controls in conjunction with PV to improve customer reliability.
- ***Transmission System Performance Analysis for High Penetration PV.*** This report focuses on the transient stability of the electric power system with high penetrations of PV under various operating scenarios including current regulations and advanced grid support functionality.
- ***Solar Resource Assessment: Characterization and Forecasting to Support High PV Penetration.*** This report evaluates the current state of the art and future needs with respect to solar resource characterization and data availability.
- ***Test and Demonstration Program Definition to Support High PV Penetration.*** This report discusses the test and demonstration activities that are required to evaluate the local distribution system impacts of high penetration PV with and without storage.
- ***Value Analysis***. This report provides a detailed methodology to assess the value of PV on the utility/wholesale side and customer side for various PV system configurations, grid architectures, ownership, business models, and operational strategies.
- ***PV Business Models***. This report develops a variety of business models for the ownership and operation of PV, both alone and combined with storage systems or controls, in the residential and commercial sectors.
- ***Production Cost Modeling for High Levels of PV Penetration***. This report uses (and modifies) standard Production Cost Modeling tools to evaluate the large scale interaction of solar electricity technologies with the existing and possible future grid, with a focus on displaced generation capacity, fuel saved, and emissions avoided by deploying varying levels of solar electric generation.
- ***PV Market Penetration Scenarios.*** This report develops a set of potential scenarios for PV market penetration within the United States between 2007 and 2015. Factors examined in developing the scenarios include net metering rules, interconnection policies, electric rate tariff levels and structures, availability of state and federal financial incentives, system pricing, and carbon legislation.

A critical goal of carrying out the RSI study has been to help define a research agenda that will enable the DOE to work with utilities and industry to develop the technologies and methods that can allow the widespread market penetration of renewable energy technologies, including storage systems, advanced power electronics, and controls into the U.S. electricity grid. Control systems are likely to include improved and innovative ways to manage power demand. The study is also striving to understand the potential impacts on the electricity grid and how to optimize systems based on benefits to both customers and utilities.

Key objectives identified in the RSI reports for DOE, utilities, regulators and industry include:

- Develop *Solar Energy Grid Integration Systems* that incorporate advanced functionality and active integration with electrical distribution systems and energy management systems, enabling utilities and/or system owners to realize the full value of the systems.

- Improve stand-alone capabilities of distributed renewable technologies with storage to improve customer reliability, enhance power quality, and provide backup power functions.
- Develop and validate remote monitoring and dispatch control platforms that will optimize renewable energy and storage system benefits. Such platforms would comprise software, sensors, and demand response controls, and would integrate utility control and financial information in concert with advanced grid technologies to assure high quality and stable power delivery.
- Utilize prototype testbeds and field deployments to evaluate key characteristics of new renewable energy systems and other distributed technologies that maximize grid value.
- Develop a comprehensive demonstration plan to ensure successful simulation, demonstration, and validation with utilities and industry stakeholders.
- Conduct detailed analysis of renewable energy system performance and grid effects through electrical T&D system modeling and simulation.
- Develop and validate best practices and software tools to facilitate T&D system planning and operation with greater deployment of renewable energy systems.
- Establish grid infrastructure design and operation methods for integrating renewable energy into localized energy networks, microgrids, and mini-grids including utility load/production control methodologies.
- Establish grid infrastructure requirements for wide-area control of distributed renewable energy systems integrated into the electrical power system.
- Develop secure communications and control protocols combining high functionality, and safety, reliability, and security (surety) features to protect against malevolent or unintentional events that could undermine grid integrity.
- Develop new solar resource forecasting capabilities over a variety of time steps, including very short term (1-3 hour) for load dispatching, day ahead for system operations, and seasonal and inter-annual for long-term system planning and cash flow analyses.
- Establish consistent codes, standards, and transparent regulatory implementation practices to ensure safe and effective PV systems integration at high penetrations. Develop secure communications and control protocols combining high functionality and surety features to protect against malevolent or unintentional events that could undermine grid integrity.

Detailed Findings

The collective efforts of the 14-report RSI study have generated more than 100 specific objectives. These span a wide range of activities from research and development on new technologies, to field testing of new systems, to ways to reduce existing and potential market barriers to distributed PV. Here we list a consolidation of many of the report findings at a higher level than in the individual reports that make up the RSI study. Drawing on the reports, internal resources, and input from outside stakeholders, DOE is developing a multi-year R&D plan to address integration issues for distributed photovoltaics. This work will build on related activities, both within DOE and in key states that are aligned with broader grid modernization efforts.

The key interim findings for achieving distributed PVs' market potential fall into six topical research areas:

1. Distributed PV System Technology Development
2. Advanced Distribution Systems Integration
3. System Level Test and Demonstrations
4. Distributed Renewable Energy System Analysis
5. Solar Resource Assessment
6. Codes, Standards, and Regulatory Implementation

Each of these research areas are discussed in the following sections.

Distributed PV System Technology Development

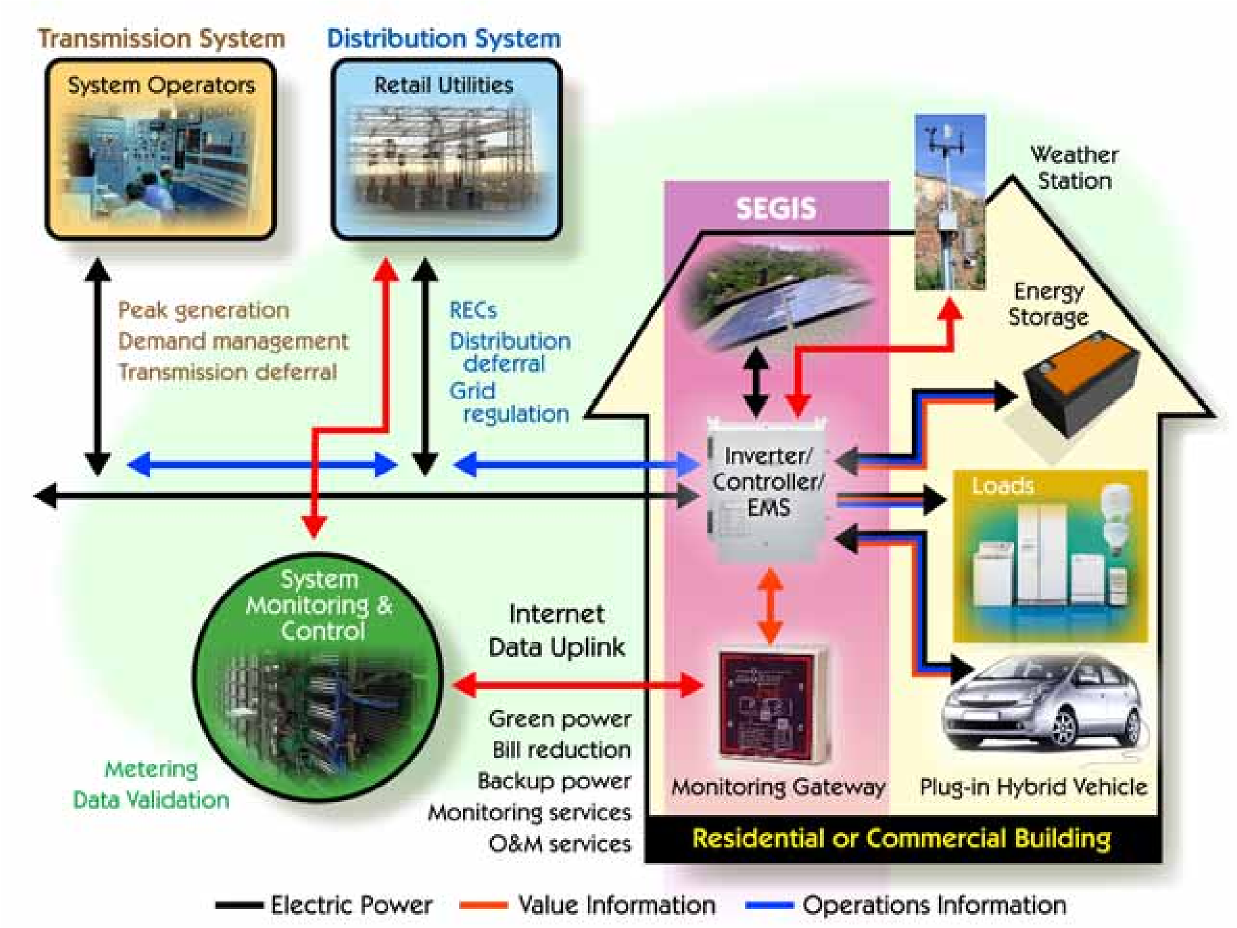
Distributed PV systems currently provide an insignificant contribution to the power balance on all but a very few utility distribution systems. With the increasing interest in PV systems and the accelerated installation of large PV systems or large groups of PV systems that are interactive with the utility grid, there is a need to insure the compatibility of higher levels of distributed generation with protection of the grid infrastructure. The variability and nondispatchability of today’s PV systems affect not only the stability of the utility grid but also the economics of both the PV system and the energy distribution system.

Integration issues (e.g., voltage regulation, unintentional islanding, and protection coordination) need to be addressed from the distributed PV system side and from the utility side for high penetration PV scenarios. Advanced inverter, controller, and interconnection technologies development must produce hardware that allows PV to operate safely with the utility and act as a grid resource providing benefits to both the grid and the owner. Advanced PV system technologies including inverters, controllers, related balance-of-system, and energy management hardware are necessary to insure safe and optimized integrations, beginning with today’s unidirectional grid and progressing to the smart grid of the future.

Objectives

- Develop *Solar Energy Grid Integration Systems* (SEGIS, see **Figure 3**) that incorporate advanced integrated inverter/controllers and energy management systems capable of supporting communication protocols utilized by energy management and utility distribution level systems.
- Develop advanced integrated inverter/controller hardware that is more reliable with longer lifetimes, e.g., 15 years mean time before failure (MTBF) and a 50% cost reduction for equivalent capability. The ultimate goal is to develop hardware with lifetimes equivalent to PV modules.
- Research and develop regulation concepts to be imbedded in inverters, controllers, and dedicated voltage conditioner technologies that integrate with power system voltage regulation, providing fast voltage regulation to mitigate flicker and faster voltage fluctuations caused by local PV fluctuations.
- Investigate DC power distribution architectures as an into-the-future method to improve overall reliability (especially with microgrids), power quality, local system cost, and very high penetration PV distributed generation.
- Develop advanced communications and control concepts that are integrated with SEGIS. These are the key to providing very sophisticated microgrid operation that maximizes efficiency, power quality, and reliability.
- Assure that communications protocols include the protections necessary to prevent accidental or unauthorized tampering that could threaten grid integrity.
- Identify inverter-tied storage systems that will integrate with distributed PV generation to allow intentional islanding (microgrids) and system optimization functions (demand control) to increase the economic competitiveness of distributed generation.
- Develop building energy system controllers that can monitor solar resource forecast, utility pricing, building loads, and associated building occupant data (workday, weekend, planned vacation) to optimize system value by controlling loads and dispatching storage.

Figure 3. The Solar Energy Grid Integration System (SEGIS) Integrated with Advanced Distribution Systems



Source: U.S. Department of Energy

Advanced Distribution Systems Integration

Where net-metering exists in the United States, PV generation can be used on-site or delivered to the grid. Under low levels of PV penetration, the grid balances the variations in supply and demand over a wide area, thus improving the economics of PV and reducing the need for additional energy storage. A critical challenge for deployment of widespread PV energy, however, is to modernize the existing distribution system that was designed, built, and operated for centralized generation. With limited capacity for reverse power flows and without controls and communication at the point of use, the existing grid is not capable of effectively integrating distributed large-scale PV generation.

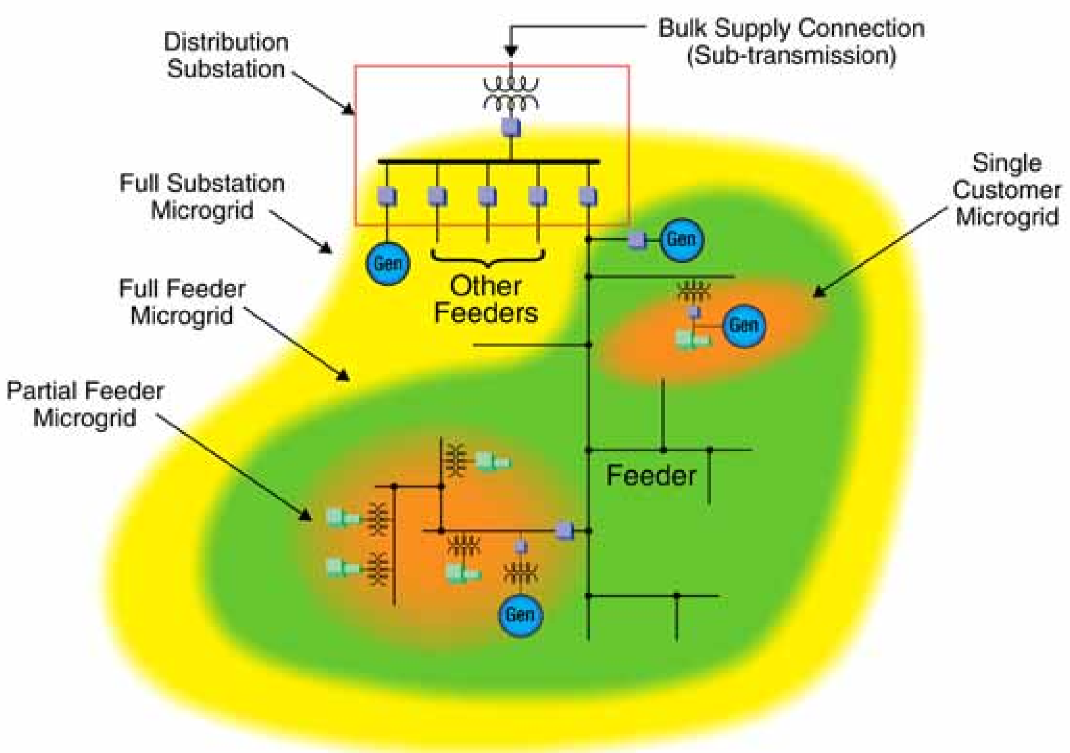
Hence a strategy is needed to move from the relatively small PV energy market of "passively interacting" systems to *Solar Energy Grid Integration Systems* that are an "active partner" in the grid. A key element of this strategy is that the PV system will help to meet system energy demand and control requirements at all grid levels including transmission and system operators.

Objectives

- Through R&D planning and coordination, seek an evolution of the distribution system that includes increased distribution automation, automated load controls, and facilitation of power quality and reliability-enhancing features.
- Develop business cases that create opportunities on both sides of the meter that lead to a *"market-driven response"* for reinventing the electric grid.
- Develop distribution systems that allow for interactive voltage regulation and VAr management, bulk system coordination of PV for market and bulk system control, protective relaying schemes designed for PV, advanced islanding monitoring and control, PV interactive service restoration, improved grounding compatibility, advanced metering with communications, and use of distributed energy storage.
- Develop microgrid technologies that may be applied in a broad range of sizes and configurations and allow distributed PV to operate autonomously with islanded resources and the distribution grid to accommodate these types of systems. (see **Figure 4)**.

Figure 4. Microgrid Examples on the Distribution System

This figure illustrates examples of possible microgrid "subsets" that could be derived on a typical radial distribution system. These microgrid subsets include a single customer, a group of customers, an entire feeder, or a complete substation with multiple feeders.



Source: Electric Power Research Institute

System Level Test and Demonstrations

A wide range of testing and demonstration is required to understand the effects of high penetration of PV systems on the grid. For instance, tests are needed to determine whether a problem exists and to characterize its extent, while other tests validate the solutions to that problem and can identify system benefits. Testing should include both controlled laboratory testing as well as field testing and demonstrations.

Laboratory-based Testing

Controlled-environment laboratory testing allows specific parameters to be accurately characterized and provides repeatable test conditions that would be difficult to replicate in the field without extensive long-term monitoring. Lab-based testing involves developing standard test procedures and requirements, evaluating solutions to emerging problems, and verifying and certifying the performance of new products.

Objectives

- Develop and validate models for specific PV system equipment, especially inverter performance models as they relate to the simulation of distribution system impacts.
- Develop laboratory capabilities for testing a variety of high penetration scenarios under conditions that are as close to real word as possible. Specific tests to be developed include evaluation of voltage regulation schemes, unintentional islanding prevention, intentional island/microgrid operation, false inverter trips due to utility line transients, reverse power flow in secondary network distribution systems, and system stability such as with variable cloud cover.
- Establish and carry out test protocols for emerging communication methods between distributed PV systems, utility grid operations, and energy management systems. These testing protocols should include methods to evaluate features such as fault tolerance (e.g., loss of communications or malevolent tampering), speed, reliability, and bandwidth of communications methods.
- Evaluate different control schemes for autonomous VAr compensation under conditions of multiple inverters. For example, evaluate the feasibility of using a voltage-neutral approach where the PV adjusts VArs to compensate for voltage rise due to real-power backfeed or a central control signal sent to multiple PVs to provide wider-area voltage control.

Field Testing and Demonstrations

Field tests can not only verify that a problem exists or a solution is effective, they can also point to issues that were not previously suspected. Field tests will require identifying candidate locations with high penetration of PV systems. These could include new residential subdivisions in which a large number of homes have PV systems, commercial systems where the PV is a significant part of the load, and utility interconnected systems that backfeed a significant amount of PV energy at the distribution level.

Objectives

- Utilize fielded systems to test a variety of non-traditional benefits including voltage regulation support, frequency regulation support, spinning reserve, and customer peak load reduction.
- Test the integration of energy management systems with PV systems and storage to optimally manage power

for commercial facilities. This may include development of predictive algorithms for loads and PV output in order to effectively manage storage.

- Evaluate the impact of relatively high PV penetration on existing distribution systems with intermediate voltage and current monitoring. This type of testing can be implemented very quickly by leveraging current market activities such as the systems being installed at Premier Gardens (see Figure 1) and Nellis Air Force Base (see **Figure 5**).
- Investigate voltage impacts, effectiveness of various solutions (especially if *Solar Energy Grid Integration Systems* with VAr capability are installed), fault contribution, and fuse coordination/desensitization.
- Investigate PV installed on undersized/overloaded primary or secondary distribution lines where the substation voltage is elevated to deal with the voltage drop (e.g., old rural feeder with new large homes).

Figure 5. 15-MW PV Installation on the Distribution Grid, Nellis Air Force Base, Nevada

Source: SunPower Corporation

Distributed Renewable Energy System Analysis

Evaluating the impacts of high levels of PV penetration on the electricity grid will require both technical and economic analysis. Analysis will also help identify potential impacts of proposed solutions on the marketplace.

Technical Analysis

To overcome technical concerns with integrating large amounts of PV into the grid, modeling and simulation tools need to be updated with appropriate models for PV system components and for distribution system analysis.

Objectives

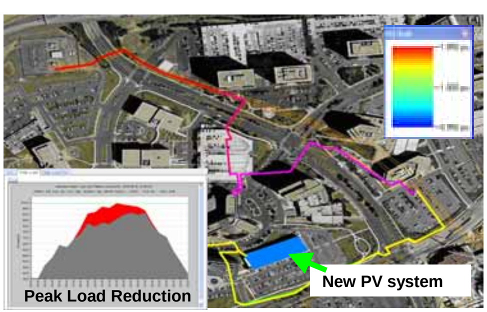
- Solve problem of ground fault overvoltage on sub-transmission system by investigating use of grounding bank transformers, special switchgear timing considerations, transfer trips in switchgear operations, and upgraded voltage ratings of devices.
- Find ways to adapt the distribution system protective relaying and fusing to deal with fault currents that arise from larger quantities of distributed PV.
- Develop new voltage regulation schemes for steady-state (slow) regulation based on communication between load-tap changing transformer, step voltage regulators, capacitor banks, and PV.
- Study the effective grounding compatibility problem associated with PV and determine the path (equipment technologies and system changes) that can be used to most cost-effectively reduce the need to effectively ground all PV on the 4-wire multi-grounded neutral distribution systems.
- Develop enhanced component models. Although some very powerful software

tools are available for distribution system simulation, the industry currently lacks detailed modeling information for distributed renewable energy sources. Simulation would benefit greatly from readily available "performance profiles" that would consist of the device's fault contribution curve, rate of output change, response to small and medium signal steps, and islanding test results.

- Create a set of benchmark cases to facilitate testing of models and associated software. Some of the confusion and unwarranted concerns about the PV generation's impact results from inconsistent and incorrect modeling.
- Develop automated screening tools that will enable evaluation of the impact of PV on the distribution system. All prospective installations could then be screened and only the ones requiring more detailed assessment would need to be further evaluated by utilities.
- Update commercial load flow and fault current calculation software to handle multiple distributed energy sources on the system. These generally include a data management system that is often integrated with a geographical information system (GIS) that is used in operations and restoration.

Figure 6. Distributed Renewable Energy System Analysis

Possible software to understand voltage profile and load reduction on electric distribution system with new PV installations



Source: National Renewable Energy Laboratory

Economic Analysis

In addition to technical concerns, understanding the customer and utility value proposition for distributed PV will be critical for integrating large quantities of PV. In many ways, the solar PV industry is where the wind industry was over a decade ago, with relatively small penetration and fairly limited understanding of the impacts of large-scale deployment onto the grid.

Objectives

- Develop best practices for quantifying the various potential costs and benefits of distributed PV including avoided generation costs, avoided transmission and distribution costs, avoided generation and T&D losses, capacity increase/peak load reduction, voltage/VAr support, phase balancing, harmonic correction, backup power/ power outage mitigation, equipment upgrade deferral, distribution equipment reliability improvements, hedge against volatile fossil fuel prices, rapid and easy PV deployment, environmental and health benefits, avoided water use, and job creation.
- Evaluate the extent to which the geographical diversity of distributed PV mitigates the short-term output variability due to rapidly changing weather conditions (such as the passage of clouds).
- Evaluate the costs associated with unit commitment errors and the impacts of increased forecasting quality.
- Examine enabling technologies and techniques, including increased spatial diversity, diversity of orientation, market-based approaches such as time-of-use and real-time pricing, and technology options such as load shifting, long-distance transmission, and various

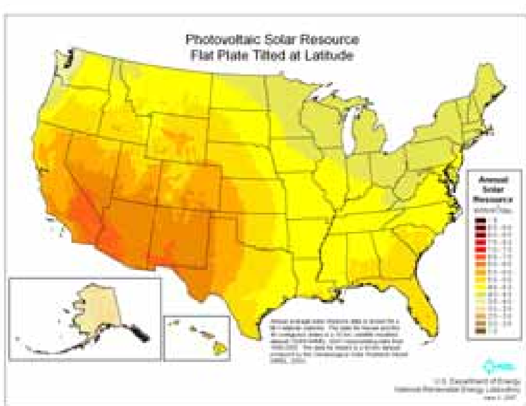
centralized and distributed energy storage technologies.

- Examine the potential for electric or plug-in hybrid electric vehicles to serve as a PV enabling technology.
- Work with state agencies (such as the California Public Utilities Commission, California Energy Commission and others) and utilities to pilot second-generation business models in which utilities own some or all of the PV system. These second-generation business models could enable utilities to tap into the value of PV and mitigate concerns about safety, operations, and revenue.

Solar Resource Assessment

Comprehensive knowledge of the temporal and spatial characteristics of the solar resource available to PV systems, as well as key related weather data, are needed to shape PV systems'/energy management systems' (EMS) operational strategies, better simulate how PV systems will behave within the grid, and to boost system cost-effectiveness.

Figure 7. High-Resolution Solar Data



Source: National Renewable Energy Laboratory

Objectives

- Develop solar resource forecasting capabilities over a variety of time steps, including very short term (1–3 hour) for load dispatching, day ahead for system operations, and seasonal and interannual for long-term system planning and cash flow analyses.
- Develop reliable, sub-hourly data sets, from both measurement systems and from model outputs; data intervals as short as one minute (or more typically, 15 minute) could be used as part of load control and load-following studies under high penetration scenarios with no storage available. Presently, only a few measurement stations in the United States provide these data, and all of the National Solar Radiation Database (NSRDB) data are hourly values. Modeled solar resource data are not available at the sub-hourly time scale
- Improve the spatial resolution of data sets, which are currently 10 km to 100 km depending on period of interest, so that resource information can be more accurately pinpointed to specific locations where grid-tied PV systems are likely to be installed.
- Develop a user-interactive data archive so that end users can create and access specialized data sets online to meet specific analytical requirements.
- Coordinate closely with modeling software and energy management systems to focus new solar radiation products in support of RSI requirements and operational strategies.

Codes, Standards, and Regulatory Implementation

The U.S. electric grid safety and reliability infrastructure is comprised of linked installation codes, product standards, and regulatory functions such as inspection and operation principles. The National Electric Code, Institute of Electrical and Electronic Engineers, American National Standards, building codes, and state and federal regulatory inspection and compliance mandates have to work hand in hand to provide a safe, reliable and robust electric T&D grid.

Codes, standards, and regulatory (CS&R) implementation have been cited as major impediments to widespread use of PV on the grid in the United States. Effectively interconnecting distributed renewable energy systems requires careful attention to ensuring compatibility with the existing grid. In the past, the electric grid was not traditionally designed for two-way flow of power, especially at the distribution level. Uniform requirements for power quality, islanding protection, and passive system participation (IEEE 1547) could help PV. In the future, we will need to develop national requirements for power quality and active participation in power system operation. In the absence of secure communications and control protocols, cyber attacks could pose serious risks as penetration grows.

Objectives

- Enable coordinated operation of all equipment on the distribution feeder. The same infrastructure can be used to enable demand-side management, implementation of flexible metering tariffs, and enhanced distribution system management.
- Establish recommended practices for modeling high penetration, intermittent renewable energy power sources and energy storage systems embedded in the distribution system.
- Develop consensus best practices that facilitate T&D system planning and operation for grid modernization, which includes provision for greater deployment of renewable energy systems.
- Develop recommendations for consideration by electricity regulators on net-metering/rate structures, microgrids, and impact study requirements.
- Improve methods/agreements for local siting, permitting, and inspection of PV systems.

RSI Study Reports

Advanced PV System Designs and Technology Requirements, Chuck Whitaker and Jeff Newmiller, BEW Engineering; Michael Ropp, Northern Plains Power Technologies; Ben Norris, Norris Energy Consulting

Advanced Grid Planning and Operations, Mark McGranaghan, Thomas Ortmeyer, David Crudele, Thomas Key, and Jeff Smith, Electric Power Research Institute; Phil Barker, NOVA Energy Specialists LLC

Utility Models, Analysis and Simulation Tools, Thomas Ortmeyer, Roger Dugan, and David Crudele, Electric Power Research Institute

Renewable System Interconnection Security Analysis, Annie McIntyre, Sandia National Laboratories

Development of Analysis Methodology for Evaluating the Impact of High Penetration PV, Jovan Bebic, GE Global Research

Distribution System Performance Analysis for High Penetration PV, Ellen Liu and Jovan Bebic, GE Global Research

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